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LANDSAT-4 BAND 6 DATA EVALUATION

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Second Quarterly Report

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Objectives:

The objectives of this investigation are to evaluate and monitor the radiometric integrity of the Landsat-D Thematic Mapper (TM) thermal infrared channel (band 6) data to develop improved radiometric preprocessing calibration techniques for removal of atmospheric effects.

Problems:

A satellite underflight was made in January; however, a mechanical failure in the film transport caused a loss of data. This problem has been corrected and underflight data will be collected as soon as data transmission resumes.

Accomplishments:

Primary data analysis this reporting period has been spent in evaluating the line to line and detector to detector variation in the thermal infrared data. The data studied was in the core area of Lake Ontario where very stable temperatures were expected. The detectors and the scan direction were taken as separate parameters and an analysis of variance was conducted. The results displayed in Table 1 and Table 2 show the detector means and variances as well as the ANOVA results. These data indicate that significant variability exists both between detectors and between scan directions. Methods to further define the form of this variability and to reduce it will be considered during the next reporting period.

The radiosonde data corresponding to the September image over the target area was received and input into the LOWTRAN Model. Figure 1 and Figure 2 were generated from the model output. These figures represent the variation in the atmospheric transmission and path radiance as a function of altitude. This type of modeled data will be compared to the underflight data in evaluating the potential use of the LOWTRAN models to evaluate Thematic Mapper data.

Significant Results:

None this reporting period.

Publications:

A draft of the paper presented at the Landsat-4 Early Results Symposium is attached.

Recommendations:

None this reporting period.

Funds Expended:

$27,192, representing 23% of the total program effort.

Data Utility:

N/A

JRS:mp

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TABLE 1

TEMPERATURE STATISTICS (°C)*

	Scan Direction 1	Scan Direction 2
1	16.97 ± 0.21	17.3 ± 0.24
2	16.92 ± 0.21	17.43 ± 0.18
3	16.96 ± 0.15	17.40 ± 0.17
4	17.19 ± 0.28	17.32 ± 0.26

* Sample Size = 200 for each detector/scan direction combination

TABLE 2

ANALYSIS OF VARIANCE FOR LANDSAT 4 THEMATIC MAPPER DETECTOR

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F(0)
Scan Direction	49.228	1	49.228	1042.23
Detectors	3.153	3	1.051	22.25
Interaction	8.046	3	2.682	56.78
Error	75.195	1592	0.047	
Total	135.622	1599		

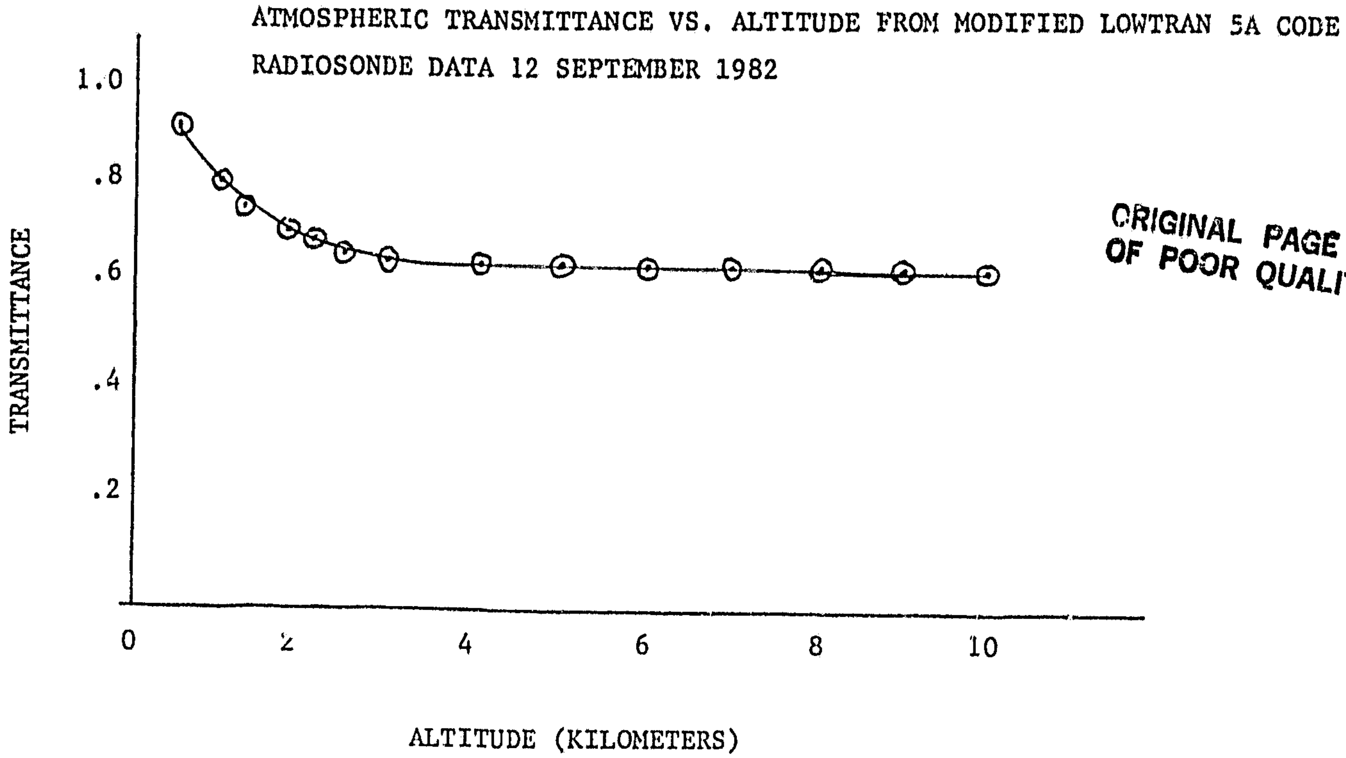

FIGURE 1

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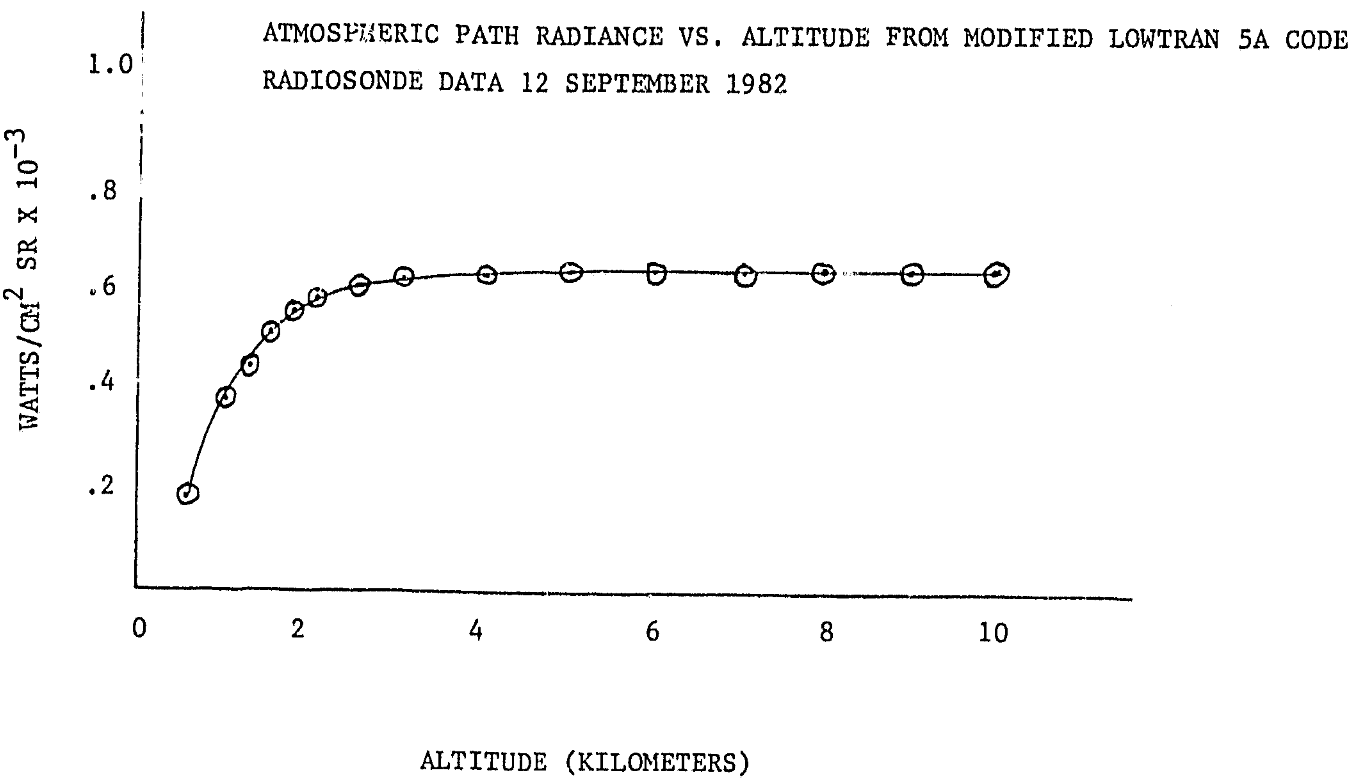

FIGURE 2

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EVALUATION OF THE RADIOMETRIC INTEGRITY OF LANDSAT 4 THEMATIC MAPPER BAND 6 DATA

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Introduction and Background

The data from the thermal infrared channel (Band 6) aboard the thematic mapper represent the highest spatial resolution thermal information yet available from space. The radiometric response function of the thermal sensor must be carefully evaluated to permit proper interpretation of these unique data. Probably the most generally accepted method for processing radiometric data from space is to correct the observed radiance or apparent temperature to a surface radiance or temperature value using atmospheric propagation models. For example using radiosonde data from the study area at the time of an overpass the atmospheric transmission and path radiance terms (τ and W_A) can be computed using AFCRL's LOWTRAN code (Ref. 1) or NASA's RADTRA code (Ref. 2). These terms can be used to compute the surface radiance from

$$W_S = (W - W_A)/\tau. \qquad (1)$$

Where; W is the observed radiance and W_S is the surface radiance which can be associated with an equivalent black body temperature (T_S).

As part of NASA's Heat Capacity Mapping Mission (HCMM) experiment the atmospheric propagation models were used in reverse in an attempt to evaluate the post launch radiometric response of the Heat Capacity Mapping Radiometer (HCMR). Bohse et al 1979, describe how surface radiometric readings were used in conjunction with radiosonde data to predict the radiance at the top of the atmosphere using atmospheric propagation models. Surface data taken with a point radiometer viewing a lake were averaged to define W_S and the atmospheric propagation models were used to define τ and W_A at the time of the overpass. Therefore the radiance observed by the spacecraft sensor W' and the radiance calculated from the model ($W = \tau \cdot W_S + W_A$) should be identical. In fact for the five dates studied the difference in observed and predicted values ranged from 4.15 to 6.14°C with an average difference of 5.24°C (radiance values have been converted to equivalent blackbody temperatures). As a result of these analysis, NASA offset the prelaunch calibration values for the sensor by -5.5°C and applied this offset to all standard HCMM products (Ref. 4).

This offset was based on the assumption that the sensor response and/or the calibration standard had somehow changed since the prelaunch calibration. Subsequent studies five months later conducted in an identical fashion indicated that the offset should be moved back toward the

original value by 3.3 to 7.7°C (Ref 5). This would essentially nullify the original offset. If we accept the initial premise of a shift in the HCMR response function we must now speculate on the possibility of long term drift in the sensor calibration. An alternative and perhaps more acceptable hypothesis is that the atmospheric propagation models are inadequate and part or all of the variance is associated with changes in the atmosphere insufficiently accounted for by the models.

Whether the sensor or the models were at fault - the fact remains that - the radiometric calibration of the data was seriously in question. Both the actual radiance reaching the sensor and surface radiance values generated by processing the raw data were in doubt.

Lest these same doubts plaque the thermal data from Landsat D, it is imperative that the radiometric response function of the sensor be carefully evaluated after launch using reliable experimental data. Since nearly all users have a requirement for surface radiance data it is also essential that the atmospheric propagation models be more carefully evaluated and refined as preprocessing algorithms. This paper describes a program to experimentally evaluate the radiometric calibration of the Landsat 4 band 6 data. This approach draws on a method employed by Schott and Schimminger, 1981 as part of the HCMM experiment to radiometrically calibrate the HCMR data. Schott and Schimminger 1981 successfully utilized an approach to radiometric calibration of HCMR data that involved underflying the satellite with an infrared line scanner. This approach enabled calibration of the satellite sensor to within 1°C of surface temperature values. By extending this technology to higher altitudes experimental radiance data suitable for radiometric calibration of the TM band 6 sensor can be generated. Repetition of this experiment will permit evaluation of long term drift in the sensor and provide a data base for the second phase of the program.

The second phase of the experiment involves evaluation of the atmospheric propagation models for radiation transfer. Along with the underflight data from phase one, radiosonde data (suitable for input to the propagation models) will be available. The propagation models can be used to predict atmospheric transmission and path radiance values as a function of altitude and at slant paths to the satellite. These same values are derivable from the empirical data gathered during the underflight. By comparing these values it should be possible to begin to evaluate any systematic errors in the models. During this phase modifications to the models based on systematic errors and/or additional surface truth data will be evaluated. If sufficiently accurate models can be defined then underflight data would not be required for continued evaluation of sensor performance. In addition satellite data could be preprocessed to produce direct surface radiance or equivalent temperature images.

TECHNICAL DISCUSSION

Data collection for this effort involves an extension of techniques successfully used to radiometrically calibrate the HCMM sensor. We will briefly describe the HCMM experiment and use this as a base for describing the evaluation of the TM band 6 sensor. To account for atmospheric effects we utilized a model involving collection of ground truth simultaneously

with satellite data collection. Great care must be taken to insure that ground truth data for a satellite sensor represents the true integrated surface radiance or temperature over the entire projected instantaneous field of view (IFOV) of the sensor. To accomplish this large areas of uniform temperature are employed -- usually water bodies. However most water bodies have significant variation in them such that integration of the temperature or radiance pattern observed is often desirable. To accomplish this on the HCMM experiment the satellite sensor was underflown with an infrared line scanner to image large areas at different temperatures. Fractions of the imaged areas could then be registered with satellite pixels and integrated to provide corresponding radiance fields (cf., Figure 1). These radiance data however are degraded by the atmosphere between the aircraft and the ground. These atmospheric effects are accounted for by a method described by Schott 1979 which involved flying the aircraft at a series of altitudes over the same target areas. This method yields the atmospheric transmission term "τ" and the path radiance term "W_A" at flight altitude and therefore permits computation of the surface radiance W_S or equivalent temperature T_S for any target imaged at the flight altitude. This method was extensively tested in blindfold experiments which showed a standard error of 0.4°C between the temperature predicted from the aircraft data and independently observed at the surface. By employing this method the true surface temperature or equivalent surface radiance of an area imaged by the aircraft and the satellite was defined by analysis of the apparent temperature observed by the aircraft. By regressing the observed radiance at the spacecraft against the true surface radiance the atmospheric transmission and path radiance terms affecting satellite data can be determined from

$$W_O = \tau W_S + W_A. \qquad (2)$$

Where W_O is the observed radiance at the satellite. In practice a range of targets largely separated in temperature provide the best fit to equation 2. The spring thermal bar in the Laurention Great Lakes provides this temperature range admirably with large areas of the lake surface (tens of km^2) differing by as much as 10 to 12°C.

The approach described above was applied to the thermal infrared data from the HCMR. In addition radiosonde data were used to run the LOWTRAN and RADTRA models and predict surface temperatures. Figure 2 is a graphic display of the results of these analyses. This figure illustrates that the experimental underflight method checks against itself as expected but that neither of the atmospheric propagation models very effectively predicted surface temperature values. This experiment yields a suitable means of absolute calibration of a satellite thermal infrared sensor when appropriate underflight data are available. It does not however provide insight into whether the satellite response calibration or the propagation models or both are at fault in the LOWTRAN and RADTRA approaches. (N.B., Because the underflight method employs ground truth it does not require a calibrated sensor, only a linear response function; i.e., it only requires that observed radiance be linear with true radiance).

The method described above can be modified to permit empirical analysis of the radiance reaching the spacecraft. The airborne sensor has been filtered to match the spectral response of the TM band 6 sensors. Therefore the atmospheric transmission and path radiance terms computed for

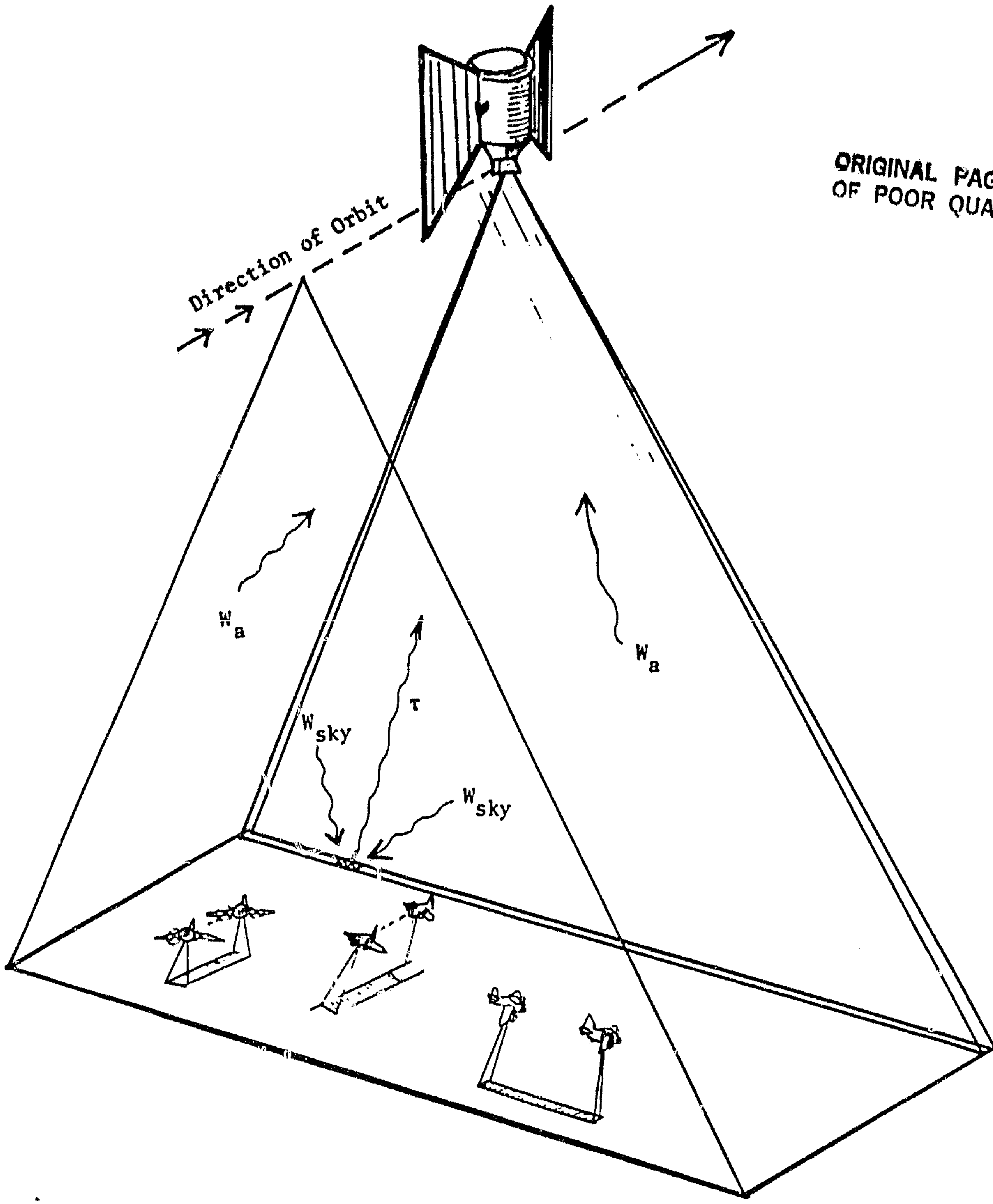

FIGURE 1. CALIBRATION OF SATELLITE IMAGERY USING UNDERFLIGHTS

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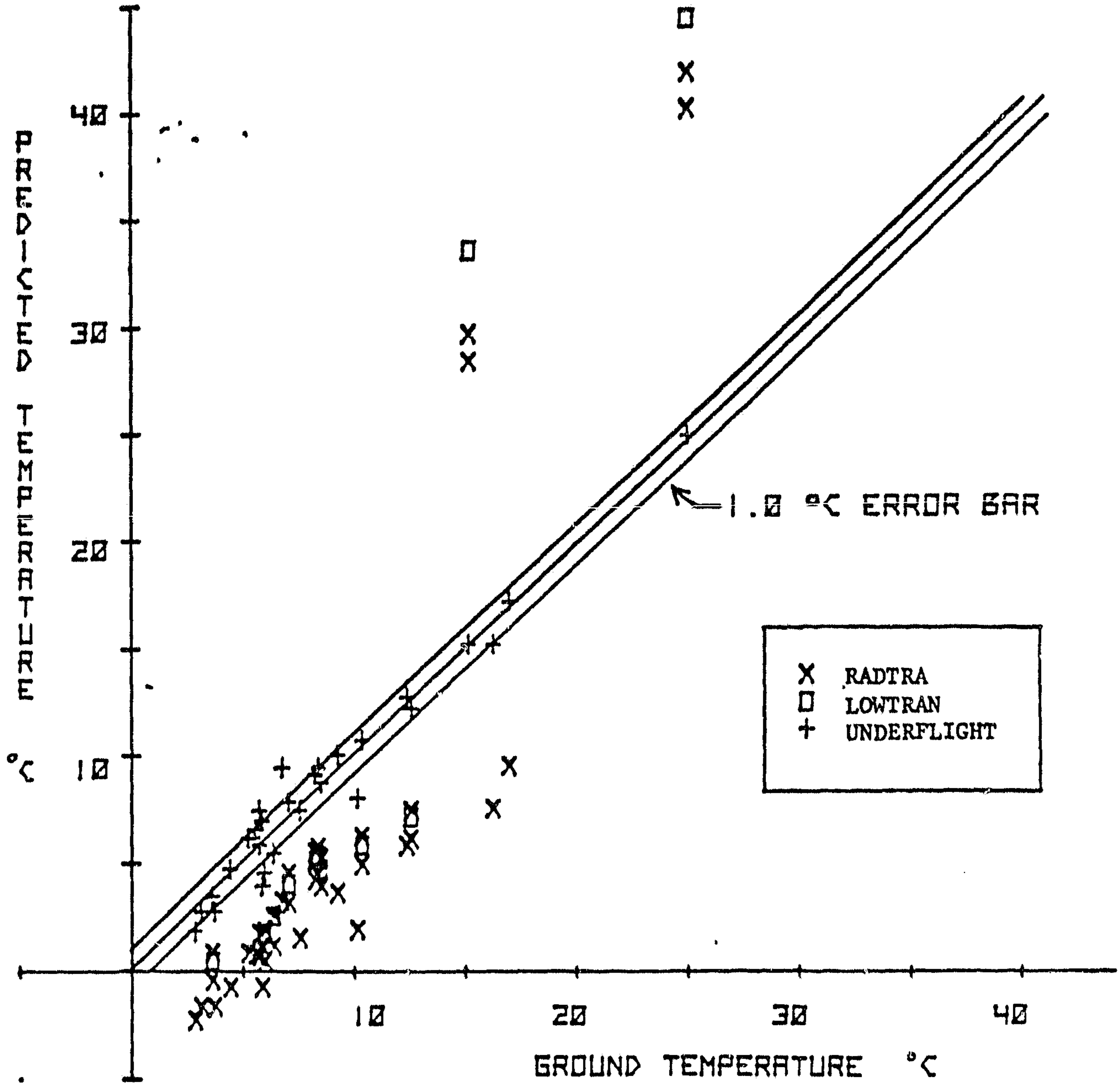

Figure 2. Plot of Water Surface Temperature vs. Temperatures Predicted by Various HCMR Calibration Methods. The Residual Error in the Predicted Temperatures Using the Underflight Calibration Technique is 1.0°C. The Residual Errors Associated With the LOWTRAN and RADTRA Models are 9.0°C and 6.9°C Respectively.

each altitude are the same terms that affect the satellite data. By flying the aerial sensor at several altitudes up to or approaching the top of the atmosphere the effective propagation terms can be directly measured or simply extrapolated with the aid of radiosonde data (cf., Figure 3). Previous studies over the target area indicated that nearly all the atmospheric effects took place below 7 Km.. This is within the range of the turbo charged Aztec C which is being used for data collection. With the atmospheric propagation terms defined in this manner the radiance reaching the satellite can be defined for any targets imaged both by the satellite and the aircraft. The satellite sensors post launch performance can then be evaluated by comparing the observed satellite radiance to the radiance values known to be incident on the sensor. Through repetitive measurements the presence of drift or the existence of any systematic shift in system performance will be verified. Since many points are available for comparison between the satellite and the aerial images the functional relationship between the radiance recorded by the satellite and the actual radiance should be definable. Thus any corrections required to affect post launch shifts in system response will be defined.

Radiosonde data collected in the study area will be accessed for each underflight. These data are used to generate atmospheric propagation terms using the models sited above. The propagation terms generated by the models and the experimentally derived terms will be evaluated to determine if the models are adequate for sensor evaluation and preprocessing of radiometric data.

As necessary, further effort will be directed at defining and developing corrections to the atmospheric propagation models to bring them into agreement with experimental data. If these models can be sufficiently improved then the method used in the attempt at validating the HCMM calibration could be used for TM band 6 verification. In addition the models could be used to preprocess TM band 6 data to provide actual surface radiance or surface temperature images.

The models would be evaluated using the underflight data. The underflight data can be used to observe the atmospheric transmission (τ) and path radiance (W_A) at each altitude sampled. In addition by interpolation through the models described by Schott 1979 the transmission and path radiance terms to any altitude and at various angles can be computed. The atmospheric propagation models are also capable of interpolating within the radiosonde data to provide transmission and path radiance data as a function of altitude and view angle. Therefore, an extensive data base will be developed for comparing the data derived from the atmospheric propagation models to the empirical data. Through statistical analysis of these data, corrections to the propagation models can be inferred. Analyses of the various underflight data sets obtained will provide information on the effects of varying atmospheric conditions on the model performance. This added dimension will enable us to look for a systematic pattern to the statistical corrections derived for an individual data set. Using these data we will attempt to develop corrections to the models either in the form of corrections to the model's coefficients or refinements to the theoretical approach. The systematic corrections developed in this manner will be applied to the satellite data and compared to the known surface radiance values derived from the

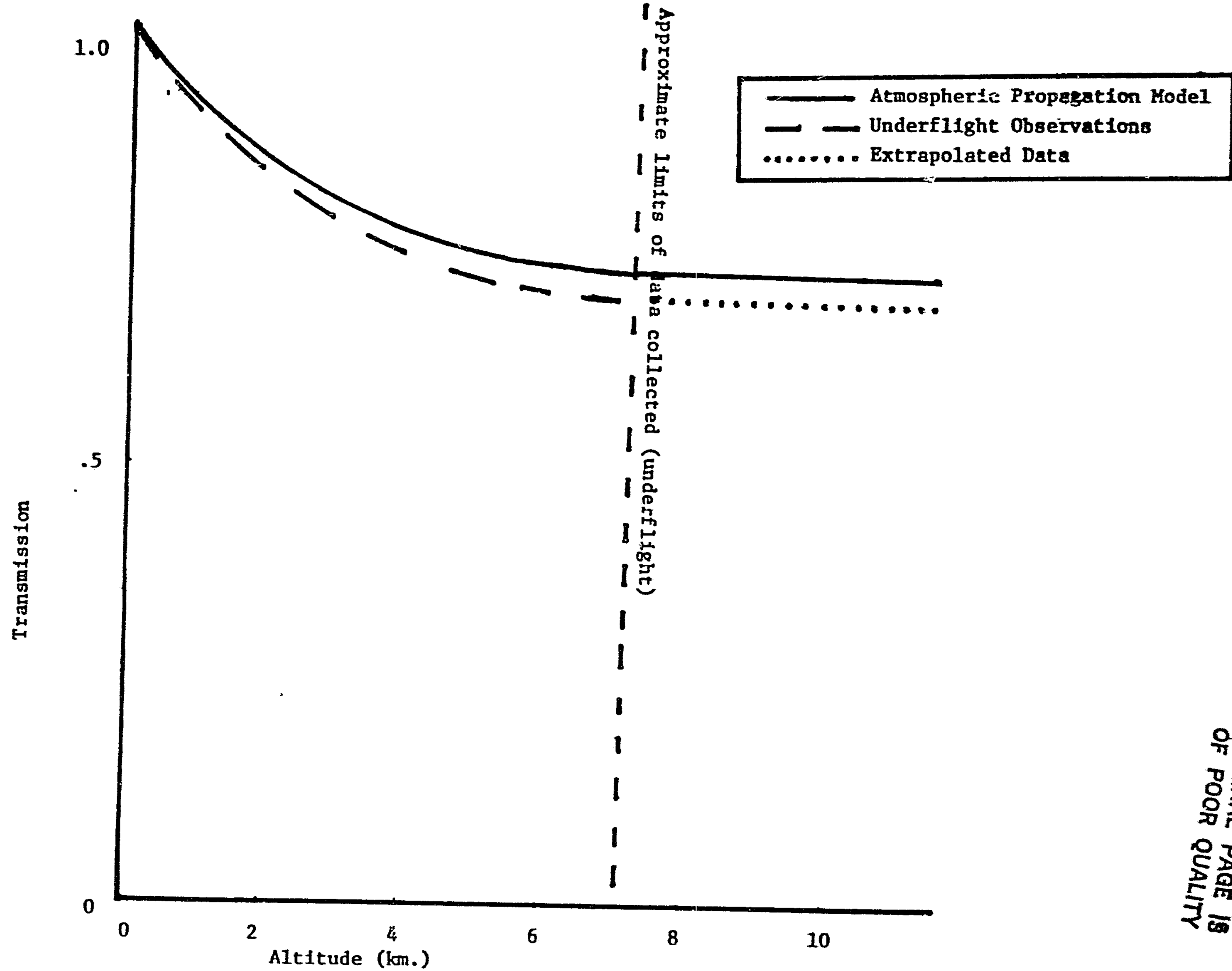

Figure 3. Plot of Atmospheric Transmission as a Function of Altitude

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underflight data. Again, these results will be analyzed to determine if the revised models are suitable for evaluation of the radiometric calibration of TM band 6 and also therefore suitable for preprocessing of the band 6 data.

To date, efforts have concentrated on modification of the infrared line scanner to match the spectral response of the TM band 6 sensor and limited efforts to underfly the satellite on clear days. The major data collection thrust is scheduled for the spring of 1983 when the large temperature gradients in the Laurention Great Lakes will insure the availability of properly dispersed data.

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